Paleoseismic Investigation of Earthquake Hazard and Long-term Movement History of the Hurricane Fault, Southwestern Utah and Northwestern Arizona
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INVESTIGATIONS UNDERTAKEN

The Utah Geological Survey (UGS) and the Arizona Geological Survey (AZGS) are cooperators on a study of the Hurricane fault, the longest and most active of several large, late Cenozoic, west-dipping normal faults in the transition zone between the Colorado Plateaus and Basin and Range physiographic provinces in southwestern Utah and northwestern Arizona. The purpose of the study is to develop new paleoseismic information that will help characterize the fault's late Quaternary behavior, test current segmentation models, and provide information critical to earthquake-hazard assessment in a rapidly urbanizing region.

UGS Investigation

Paleoseismic Analysis

Trenching: There are six sites on the Ash Creek segment (Stewart and Taylor, 1996;figure 1) where fault scarps are formed on unconsolidated deposits (Pearthree and others, 1998). Only the Shurtz Creek site was previously known (Averitt, 1962). Two new sites (Water Tank and Kannarraville) are south of a right bend in the fault at Murie Creek, one site is at the bend (Murie Creek), and two sites (Bauer and Middleton) are north of the bend (figure 1). The UGS considered all six locations for trenching and selected the Murie Creek site as the preferred trenching location. However, the site is on private property, and while the landowner would allow surface investigations (scarp profiling and soil pits), he would not allow trenching.

We reevaluated the remaining five sites and selected the scarp at Shurtz Creek for trenching. Shurtz Creek was originally rejected because the ground surface is covered with large boulders which we believed might also be present in the subsurface. Trenching at Shurtz Creek commenced in September 1999, and immediately encountered large boulders in the subsurface which limited the trench depth to less than 1.5 meters and prevented exposing the fault zone. Moving to one of the remaining four scarps along the northern part of the fault was rejected because we had already selected what we considered to be the two sites with the best chance of providing useful paleoseismic data and because of access problems at the other locations.

Dating Stream Alluvium and Alluvial-Fan Deposits: Lacking a viable trench site on the north end of the Hurricane fault, our efforts refocused on dating unfaulted young stream alluvium where it overlies the fault zone at the Middleton and Bauer sites(figure 1) and faulted young alluvial-fan sediments at Murie Creek. Dating these deposits will provide limiting ages for the timing of the most recent surface-faulting event at the north end of the fault. Stream cuts at all three sites expose the sediments of interest. We prepared aerial-photograph geologic maps of the sites and detailed descriptions of soil profiles at each location to determine if the deposits could be differentiated on the basis of soil-profile development. Utah State University (USU) analyzed bulk samples from the soil-profile horizons for grain-size distribution and total carbonate content. Paleo Research Laboratories (PRL) processed bulk samples from select stratigraphic intervals and identified the organic matter present. We submitted detrital charcoal identified by PRL from each site to Beta Analytic Inc. for accelerator mass spectrometry (AMS) radiocarbon dating.

Developing Long-term Fault-slip Data from Displaced Basalt Flows

The UGS is using geochemical, paleomagnetic, and petrologic data to correlate displaced basalts across the Hurricane fault and to determine the amount of backtilting toward the fault for net-slip calculations. We have submitted samples to the New Mexico Geochronology Research Laboratory (NMGRL) for $^{40}Ar/^{39}Ar$ radiometric dating to determine the age of correlative displaced basalts and hence, the time period over which the slip occurred. Dr. Michael Hozik of the Richard Stockton College of New Jersey is performing the paleomagnetic analysis; Professor Stanley Hatfield of Southern Utah University is conducting the geochemical and petrologic study.

Paleomagnetic analysis: Differences in the orientation of the remnant magnetic vector between basalts in the hanging wall and footwall of the Hurricane fault provide a measure of the backtilting of the hanging wall toward the fault. Once the extent of the backtilting is known, the effects of near-field deformation can be accounted for in slip-rate calculations for the fault. Dr. Hozik collected 437 basalt core samples from 42 sites(figure 2) along the Utah portion of the fault and analyzed the samples in the paleomagnetic lab at Richard Stockton College.

Geochemical and petrologic analysis: Professor Hatfield collected 67 samples for geochemical and petrologic examination along the Hurricane fault, most at locations coordinated with Dr. Hozik's paleomagnetic sampling program. He sent the samples to the Washington State University GeoAnalytical Laboratory (WSUGAL) for major, minor, and trace element x-ray fluorescence spectroscopy (XRF) analysis. At a later date, the UGS submitted additional samples to WSUGAL from the MP-35 volcanic cone (MP-35; figures 1 and 2), the remnant of a volcanic cone near the midpoint of Black Ridge (MH; figure 2), a repeat sample from a basalt flow in Grass Valley (GVN-2;figure 2), from a basalt flow sampled for $^{40}Ar/^{39}Ar$ radiometric dating at the base of the Black Ridge near Toquerville (ACG;figure 2), and from a basalt flow high on a cliff on the north side of Cedar Canyon above Coal Creek 5 miles east of Cedar City (CCB; figure 1).

$^{40}Ar/^{39}Ar$ age determinations: We submitted three basalt samples for $^{40}Ar/^{39}Ar$ age determinations. Two samples are from key locations along the Hurricane fault (GVN-2 and ACG;figure 2) where geochemical and topographic affinities indicated the basalt flows on either side of the fault can be correlated with a high degree of certainty. The third sample is from the basalt remnant in Cedar Canyon above Coal Creek on the footwall of the Hurricane fault (figure 1). We chose to date this flow because it rests directly on paleo-Coal Creek stream sediments ~420 meters directly above the present Coal Creek stream bed. Coal Creek flows westward to Cedar Valley and crosses the Hurricane fault at the mouth of Cedar Canyon. Erosion on Coal Creek is directly affected by changes in the stream's base level caused by displacement across the Hurricane fault. The rate of downcutting since the basalt remnant was emplaced serves as a proxy slip rate for the Hurricane fault.

Arizona Geological Survey Investigation

The AZGS is investigating the late Quaternary behavior of the Shivwitz section (figure 3) of the Hurricane fault, which is south of the Arizona-Utah border and north of the Grand Canyon (Pearthree and others, 1998). The AZGS used aerial photography and on-site reconnaissance to identify a trench site and other locations for detailed geomorphic mapping, topographic scarp profiling, and soil description and analysis. The steepness of the faulted colluvial surfaces in the northern part of the Shivwitz section precluded trenching investigations in this area, so we concentrated on the southern section where faulting had offset less steep alluvial fans.

RESULTS

Utah Geological Survey

Paleoseismic Investigations

Soils formed on unfaulted alluvium at the Middleton and Bauer sites are poorly developed. They exhibit Bk horizons expressed as weak Stage I carbonate development in both coarse- and fine-grained horizons, some rubification in Bw or weak Bt horizons, and generally weak to no soil structure. The soil formed on the faulted alluvial fan at Murie Creek is less well developed, with thin, poorly developed AB and Bw horizons; very weak Stage IA carbonate development; and no soil structure. The USU soils laboratory data confirmed an increase in $CaCO_3$ content in the Bk soil horizons. The laboratory data also show small (generally < 10%) increases in clay content in some soil-profile horizons. However, the soil profiles at all three sites are formed on stacked sequences of flood and/or debris-flow deposits that exhibit wide textural variations, so vertical changes in clay content do not necessarily reflect post-depositional soil forming processes and are not considered a good indicator of relative soil age.

Machette (1985a) described a soil chronosequence formed on alluvial terraces in the Beaver Basin approximately 60 miles north of our three sites. Climatic conditions there are generally similar to our study area; however, soil parent materials are volcanics and granitic rocks in the Beaver Basin as compared to chiefly clastic sedimentary bedrock at our sites. Machette (1985a, 1985b) assigned an age of latest Pleistocene (12,000-15,000 yr) for soils in his study area exhibiting carbonate stage development similar to the Middleton and Bauer sites. The soil formed on the Murie Creek alluvial fan is qualitatively less well developed than those at the Middleton and Bauer sites, but the difference is a matter of relative age; a quantitative estimate of how much younger cannot be made using soil-profile information alone.

Conventional AMS radiocarbon ages on detrital charcoal collected from unfaulted alluvium at the Middleton and Bauer sites are 1710±40 B.P. and 420±40 B.P., respectively. They bracket the conventional AMS radiocarbon age obtained on detrital charcoal from the Murie Creek faulted alluvial fan, which is 1220±40 B.P. Analysis of this apparent discrepancy in the radiocarbon ages of faulted and unfaulted sediments represents current work in progress on this project.

Developing Long-term Fault-slip Data from Displaced Basalt Flows

Paleomagnetic analysis: All Black Ridge samples yield the same magnetic direction, suggesting that the flows are within the same paleomagnetic time interval. On the hanging wall, localities far from the fault such as PGW and LC (figure 2) yield magnetic directions indistinguishable from those on Black Ridge. Results from ACI, ACN, and ACS (figure 2) indicate significant reverse drag adjacent to the fault. The amount of reverse drag is larger near Toquerville than at ACI. The western side of the Pintura graben suggests block rotation away from the Hurricane fault, presumably controlled by faulting in the graben and on other faults farther west. Analysis of the basalts at Pah Temp hot springs (PT) and RT-59 show less than 10 degrees of rotation toward the fault between the two sampling sites.

Geochemical and petrologic analysis: Analysis of minor and trace element geochemistry provides definitive correlation of some basalt flows across the Hurricane fault in Utah. Three distinctive geochemical basalt groupings with flows on both the footwall and hanging wall of the fault exist along the Ash Creek segment north of Toquerville. Three geochemical basalt groupings also exist farther south along the fault near Grass Valley on the Anderson Junction segment, but only one group has correlative flows on both sides of the fault. The petrology of the basalt flows along the Hurricane fault is highly variable and was not diagnostic in identifying correlative flows either alone or when used in conjunction with geochemistry.

^{40}Ar/^{39}Ar age determinations: We have received ^{40}Ar/^{39}Ar age determinations for two of the three basalt samples submitted to the NMGRL for analysis. The ages are 1.47$\pm$0.34 Ma for the sample from Grass Valley North (GVN-2) and 0.81$\pm$0.10 Ma for the sample collected from the fault footwall at the south end of Black Ridge (ACG). Integrating the results of these age estimates with geochemical and paleomagnetic data from those areas represents current work in progress on this project.

Arizona Geological Survey

The AZGS studied seven faulted alluvial-fan sites to measure the amount of vertical surface displacement and estimate the age of the surfaces. They measured carbonate rind thickness profiles in soils (Vincent and others, 1994) and used a calibrated rind thickness versus surface-age relation constrained by cosmogenic isotope dating (Stenner and others, 1999) to estimate surface age. The results of 15 topographic profiles and 8 surface age estimates and the estimated slip rates are shown in table 1. The profile locations are shown in figure 3. Note that the slip rate appears higher when determined using younger geomorphic surfaces.

Profile number	Vertical surface displacement estimate, m	Surface age estimate, ka	Slip rate, mm/yr
1	4.2	8-15	0.28-0.53
2	9.3	74-130	0.07-0.13
3	7.4	n.d.	
4	7.4	80-138	0.05-0.09
5	4.9	8-15	0.33-0.61
6	2.0	n.d.	
7	4.0	15-33	0.12-0.27
8	4.3	n.d.	
9	6.5	n.d.	
10	2.7	8-15	0.18-0.34
11	3.9	n.d.	
12	1.6	n.d.	
13	6.4	n.d.	
14	2.6	47-89	0.03-0.06
15	2.8	47-89	0.03-0.06

Table 1. Determination of slip rate using vertical surface displacement and estimated surface age.

The AZGS selected their trench location based on reasonable access for digging equipment, the relatively simple morphology of the scarp, and the likelihood of not encountering large boulders. The trench was excavated at the location of Profile 7(figure 3). Figure 4 shows a log of the entire trench and figure 5 is a detailed view of the fault zone. The trenching investigation revealed a single fault trace with evidence of at least two surface-rupturing events. Preliminary retro-deformation analysis suggests that the most-recent-event displacement on the fault was 1.9 to 2.1 meters. Stratigraphic units could not be correlated in the trench from the footwall to the hanging wall to estimate total displacement. A soil pit 10 meters downslope of the trench showed evidence of about 60 centimeters of burial of a unit on the hanging wall that is similar to a unit on the footwall. These results suggest that this late Pleistocene alluvial fan has been displaced a total of 4.6 to 4.9 meters in two surface-rupturing events and that the penultimate event displacement may be ~2.5 meters. The AZGS submitted two bulk soil samples to PRL for identification of organicc material.

The AZGS sampled the only displaced basalt flow on the Shivwitz section as part of the slip rate investigation along the fault. The basalt flow erupted from Moriah Knoll (figure 3) and was interpreted by Billingsley (1992) to be displaced approximately 130 meters by the Hurricane fault. The only age estimate of the Moriah Knoll flow is that it rests on the same erosional surface as the 0.83±0.28 Ma Antelope Knoll basalt. Poor whole-rock K-Ar ages of 2.3±1.5 Ma and 1.5±1.5 Ma of the Moriah Knoll basalt are not considered reliable for estimation of the long-term slip rate. To aid in correlating the basalt across the fault the AZGS submitted 11 basalt samples to WSUGAL for XRF analysis, and received the results as this summary was being written. When the correlation of the displaced portions of the flow is understood, a sample will be submitted for $^{40}Ar/^{39}Ar$ dating.

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REPORTS PUBLISHED

Preliminary results of this investigation will be presented at the Geological Society of America Annual Meeting in Reno, Nevada on November 16, 2000, and at the Seismological Society of America Annual Meeting in March, 2001.

AVAILABILITY OF INFORMATION

Contact William R. Lund at (435) 865-8126, lund@suu.edu for information regarding the data generated for this project.

NON-TECHNICAL PROJECT SUMMARY

The Utah Geological Survey and the Arizona Geological Survey are cooperating on a research project to evaluate earthquake hazards on the long, active Hurricane fault in southwestern Utah and northwestern Arizona. In Utah, we are dating unfaulted stream deposits that directly overlie the fault and young alluvial-fan sediments that are faulted in an attempt to bracket the timing of the most recent surface-faulting event. We are also working out the long-term (past approximately one million years) slip history of the Hurricane fault by studying the chemical, mineral, and magnetic characteristics of basalt flows displaced by the fault. We will date the displaced flows that can be correlated across the fault on the basis of their chemical, paleomagnetic, and petrologic characteristics. Knowing the age of the basalts and the amount they are displaced will allow us to calculate long-term slip rates (displacement/time) for the fault. In Arizona, we have surveyed fault-scarp profiles at several localities along the fault, described soil development on faulted alluvial-fan deposits to estimate surface ages, and used that data to estimate fault slip rates. We have also excavated a trench to determine the number of faulting events, fault displacement, and earthquake timing of the last two surface ruptures on this part of the fault.

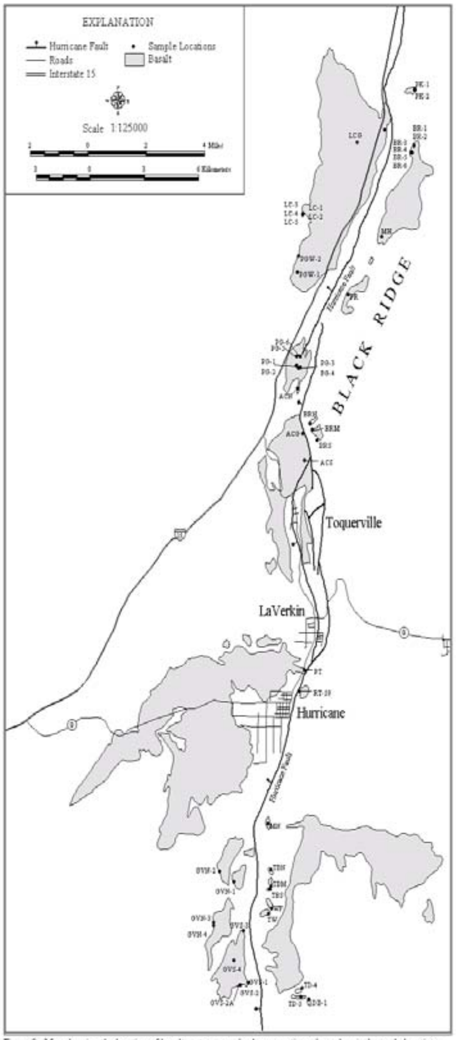

Figure 2. Map showing the location of basalt outcrops and paleomagnetic and geochemical sample locations along the Hurricane fault in Utah.

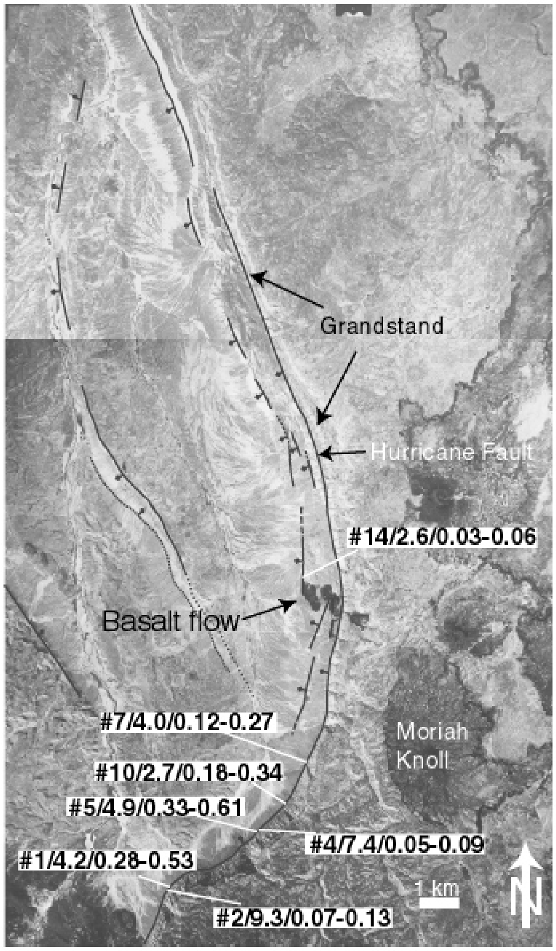

Figure 3. Mosaic of NASA high-altitude aerial photography of the Shivwitz section of the Hurricane fault zone. The fault strands from Billingsley and Workman (2000) and from reconnaissance from Pearthree and Amoroso. Faults are dashed where approximate or inferred, dotted where concealed. Shown is a compilation of the vertical surface displacement observations made during the last year (the format is profile #/surface offset in m, slip rate in mm/yr). A slip rate of 0.1 to 0.3 mm/yr was determined (using similar methodology) at Cottonwood Canyon 25 km to the north of this portion of the Shivwitz section. Profile #7 shows the location of the trench site.

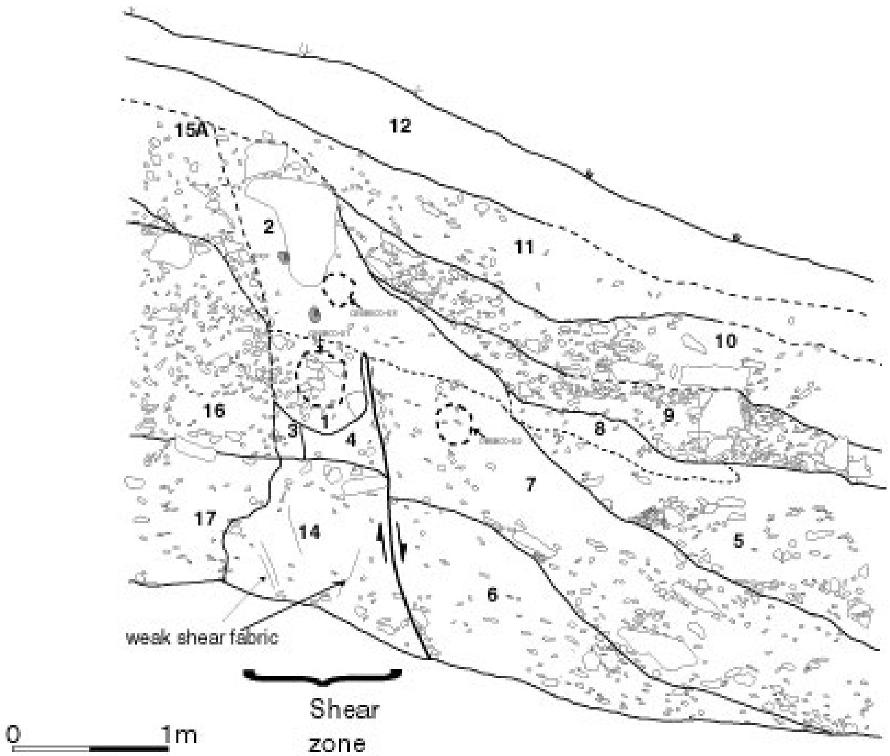

Figure 5. Detailed view of the fault zone. Unit 2 is the most-recent-event wedge. Unit 7 is the penultimate wedge, which has been displaced by the fault. The top of Unit 7 projects to the top of the sheared fabric of Unit 4.